

NEW ZEALAND GEOTHERMAL INVESTIGATIONS - DRILLING INTO THE EIGHTIES

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ABSTRACT

Over the past 3 decades, some 243 wells (180 km [112 mi]) have been drilled in various fields within New Zealand to investigate and utilize geothermal energy. This number does not include wells drilled for minor industrial and domestic uses. Drilling and completion techniques have been evolved such that no structural failures or uncontrollable blowouts have occurred with wells drilled in the past 10 years. However, there is still room for further improvement to effect more rapid and economical completion of future wells.

Drilling techniques, equipment, and materials currently in use in New Zealand are described, including surface and downhole drilling equipment, drilling fluids, cementing, and casing programs, together with proposed improvements. Recent work, including drilling a deviated well, recementing production casing after the original cementing had failed, cementing a sleeve into a well which had broken casing, removing calcite deposition from a production well, and isolating a cool inflow into a well, thus bringing the well back into production, is also described. Proposals to modify an existing well, enabling separate production from two production horizons, are outlined.

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Drilling Equipment

The majority of New Zealand wells have been drilled with National T12 drilling rigs. Failing 1500 rigs have been used for consolidation grouting of most sites, for drilling wells to 600m and carrying out shallow well maintenance. A Continental Emsco GC350 has drilled three deeper wells and deepened one well twice (but in opposite directions).

Surface equipment is standard oilfield equipment with a few necessary modifications. Forced draft cooling towers are used to cool the drilling mud. Blowout preventers (i.e. gate, annular and rotating) are fitted with high temperature sealing elements (Buna 'N'). Recently an automatically controlled choke line has been installed. This unit is designed to limit the maximum wellhead pressure developed after a flowback to a preset level hence reducing the risk of a flow outside the shallower surface casings. This unit is being improved to limit the return-flow rate within preset levels to facilitate water drilling into a reservoir wherein reservoir pressures exceed normal hydrostatic pressures (specifically in the Ngawha field).

A relatively low grade of steel is used in the drillstring (Grade E) to reduce susceptibility to hydrogen embrittlement. Until recently replaceable shrink grip tooljoints have been used to allow for high tooljoint wear. However, through their non-availability new drillpipes are fitted with welded, hard-banded tooljoints. Surprisingly casing protectors run on the drillpipe seem to be giving acceptable performance in spite of the temperatures encountered.

With recent drilling penetrating further into the highly disturbed sedimentary basement greywackes and argillites encountered in New Zealand, well deviation has become a problem which, in some cases, has prematurely terminated drilling. Measures to counter this including running a near bit reamer, short stiff drill collar (e.g. 2.5m of 7" O.D in 7 $\frac{1}{8}$ " hole) with a number of fixed blade stabilisers above, but have been met with only moderate success. In spite of the "stiff" string, deviations of 25° are still encountered.

Because of the higher bit cost and doubts about seal performance under heat, sealed bearing bits have been avoided for many years. However recent drilling has shown improved drilling economics where sealed bearing bits are used. As most New Zealand drilling encounters a large variety of formations ranging from hard abrasive volcanics to soft mudstones and breccias, with different strata occurring within short drilling intervals, bit selection

introduced to reduce the solids in the mud. Additional mud storage will allow for improved mud hydration and greater mud recovery during cementing operations. Improved mud cooling will be achieved by increasing circulation rates over the cooling tower and by the introduction of a second cooling tower where necessary.

Circulation losses are treated in traditional manner using gel plugs, gunk plugs, cement plugs and lightweight viscous cement plugs all with loss-circulation materials. Where losses cannot be sealed within a reasonable time, that section of drilling must be completed by drilling on with water, without returns. However, such action compromises the competence of subsequent casing cementing and should only be taken as a last resort.

Any improvement in techniques and materials which will effectively seal loss zones will result in very significant savings in rig, personnel and material costs.

With an increasing awareness of the environmental effects of drilling fluid effluents, there is a growing need to reduce the total volumes requiring disposal and to treat the waste in such a manner that the effects are minimised. The products of primary concern in natural waterways are the suspended colloidal solids, chromium ions from mud chemicals, alkalinity from caustic soda and cement, and the discoloration from mud chemicals. In New Zealand a flocculant and a coagulant is added to the effluent as it passes from the site to a two stage settling pond. The first stage accumulates all of the drilled solids and some of the drilling mud and cement solids. The second stage, being less turbulent than the first stage, collects a large proportion of the remaining colloidal solids. The resulting effluent contains a few hundred ppm of suspended solids and, with suitable dilution to reduce the concentration of dissolved solids, is currently acceptable for disposal into most natural waterways.

Total pond capacities are approximately 1000 cu.m. However, cheap effective means to eliminate or reduce the above contaminants will reduce site construction costs.

Casing Cementing

The majority of cementing has used Ordinary Portland cement with 3% low-yield bentonite added dry with the cement. Where return temperatures exceed 40°C up to 0.4% (by weight) of retarder is also added. While current technology would require additives (pozzolan, silica flour etc.) and pre-hydration of bentonite, a lack of blending facilities and on site tank storage have precluded these to date.

However, the emphasis has been on effective placement of cement outside the casing. To achieve this cement is

is somewhat difficult. Consequently bits are sometimes changed before being fully worn. Further, when drilling a new field a large number of cores are taken (typically 10) which does little to enhance the economics of running long life bits if they cannot withstand numerous reruns into a hot well.

Generally, downhole hydraulically operated tools do not perform well. The high temperatures reduce the life of oil seals and cause problems with oil expansion in many tools. Consequently mechanically operated tools have performed well under heat e.g. fishing jars, overshots, pipe cutters, retrievable casing plugs and deviation survey equipment. Conversely hydraulic jars, oil filled bumper subs and oil filled survey equipment have performed poorly under heat (recent use of a heat shield has overcome the problems with the oil filled directional survey equipment).

Drilling Fluids

Water based muds are used utilising bentonites manufactured in New Zealand. Two bentonites are available one being a low yielding sodium bentonite and the other a normal yielding modified calcium bentonite with the latter being the more expensive.

The lower grade bentonite provides a higher mud density without the addition of weighting materials. However, it does have a relatively high solids content and is likely to inhibit penetration rates in lower hole drilling. Consequently a compromise is made wherein the lower grade bentonite is used for top hole drilling and a mixture of both bentonites is used for lower hole drilling.

Mud treatment is confined to modified lignosulphonates and lignites for viscosity and water loss control. Defoamers are used where mud is heavily treated during the drilling of hotter sections of the wells. Diesel is only used when endeavouring to free stuck pipe.

In the past, rig crew have maintained the mud quality based on basic rig mud-laboratory measurements. This system depended largely on past experience and was reasonably successful. However, the recent introduction of a mud technician into the organisation has resulted in more consistently uniform drilling fluid thus reducing the quantities of mud dumped through overtreatment. He has probably also reduced the incidence of stuck drillstring and of loss of circulation.

Current proposals to improve the drilling mud are directed to better handling of the mud while on the surface. Double tandem shaleshakers and a mud cleaner are being

circulated through the casing until the S.G of the return from the annulus exceeds 1.6. Only then is the cement displaced from the casing. If circulation is lost either before or during the cementing operations, cement is also pumped down the annulus until a seal is effected. Up to four or five times the theoretical volume of the annular space may be required to obtain a seal. Nevertheless the use of such quantities is considered fully justified.

The main objectives of cementing are seen as giving adequate lateral and longitudinal constraint to the casing to resist stresses induced by thermal and hydrostatic effects and to prevent fluid flow in the annulus outside the casing (particularly from the casing shoe to the surface!) Thus inadequate cementing would be expected to result in casing movement or failures (fractures and/or collapse) and significant fluid flows either up or down the various annuli. Of the failures that have occurred in New Zealand the greater majority can be attributed to poor placement of cement or incompetent casing rather than to loss of cement strength (although minor annular gas flows are common, generally they do not increase with time and are considered acceptable).

Circulation losses, either from unsealed zones prior to running casing or from formation breakdown during cementing, are a major problem and contribute to unsatisfactory cementing and additional costs of cementing time and materials.

In addition to effective placement it is important that surface equipment ensures high quality control - a few litres of high W/C ratio slurry entrapped between casings can have devastating results.

Consequently further advances in cementing should concentrate on more effective sealing of loss zones and more efficient cement placement. Reduction of dynamic viscosity, loss of filtrate to permeable strata (which can cause annular bridging) and reduction of slurry density will all serve to reduce bottom hole pressures thus increasing the chances of completely filling the annular space. Identification and testing of suitable temperature-resistant additives is required and will be done on a limited basis in 1981.

Nevertheless if additives are available which will reduce strength retrogression under elevated temperatures without compromising the above requirements then they can only be beneficial. The coming 12 months will see further research into the effectiveness of materials available in New Zealand to reduce such retrogression.

Casing cementing in New Zealand should also improve with the recent acquisition of bulk pressurised tanks (enabling

blending of dry materials) and a triplex cementing unit complete with a facility to remix slurry during the cementing operation (providing high displacement rates and improved slurry quality control).

Well Completions

Current investigative wells are being drilled to 1200-1600m. They have 22" (to 40m), 16" (to 120m), 11½" (to 250m) and 8½" (to between 600 and 700m) cemented casings and are completed with 6½" slotted liner to bottom. The liner, which sits on well bottom and extends 10-20m above the 8½" shoe, is uncemented. Slotting is 53-20mm x 50mm slots/ft. Liner connections are internally and externally flush to facilitate easy cleaning of deposition and withdrawal of the liner.

The wellhead is completed with an expansion spool and parallel slide master valve fixed to the 11½" casing. The expansion spool allows for minor expansion of the 8½" casing and is fitted with a 2" side outlet which is used when quenching the well prior to a drilling workover and to bleed a continuous flow of steam from the well when not in production thus keeping the well in a hot condition. Keeping a well hot assists the longevity of the casing in that it reduces thermal cyclic stresses between shut and discharging conditions and reduces the susceptibility of the steel to hydrogen embrittlement. Refer fig 1.

During the coming 10 months the GC350 is to be upgraded to drill to 3,000m. Included in the upgrading will be improved facilities to monitor drilling parameters and drilling fluids. Mechanisation of drilling make-up and breakout tools is expected to reduce accidents to drilling personnel and to extend drillstring life. With the use of a greater capacity rig the 8½" casing strings will be replaced by a 22"/18"/13½"/9½" combination with 7½" liners. Casing depths and final well depths will also increase.

Deviated Drilling

A few wells have been deviated for various reasons. The first was to successfully intersect and seal a casing fracture which had resulted in a blowout. Subsequent wells were deviated to intersect predicted faults with variable success. Broadlands well BR24 originally drilled to 1248m was deepened to 1843m during which deviation increased to 24°. As the deepening did not improve production and permeability was predicted in the opposite direction, the well was deviated from 738m to 1538m towards the permeable feature. Where desired deviation did not occur naturally it was corrected using a conventional whipstock system. Such a system is time consuming and hence expensive.

Kawerau well KA30 was constrained in its surface location between a nearby scenic reserve and the close proximity of the predicted reservoir boundary. A 2° deviation at 237m was developed to 40° at 928m by judicious selection of bit weight and stabiliser location. Some directional control was possible with variation in rotary revs. The well was completed at 1215m with some 327m horizontal displacement into the reservoir. As the well produces in excess of 500 tonne/hour under test, the increase in drilling cost of 10% to deviate the well appears well justified.

Recementing of a Section of Casing

Kawerau Well KA10 was originally drilled 12¼" to 635m and cased with 322m of cemented 8½" with slotted 8½" from 334m to 607m. The well was later deepened 7½" to 1004m and a 6½" liner was set on bottom. The liner extended to above the slotted 8½" and was slotted over the deepened section of hole only thus restricting production from the original section of open hole.

When temperature runs showed a uniform temperature below 120m a downhole spinner was run to identify any in-hole circulation. Two flows into the liner were identified - one into the top of the liner at 295m and another into the top of the slotted section of liner at 633m. These results were interpreted as showing a flow of water from 120m down the previously cemented 8½" - 12¼" annulus.

A workover was initiated to recement the annulus and to further deepen the well in an endeavour to bring the well back into safe production. The liner was pulled and a locally fabricated drillable open hole bridging tool was cemented into open hole at 639m. Some 19 batches of S.G. 1.73 cement totaling 42 cu.m were used to progressively plug the open hole from 639m back to 343m (10m below the upper slots in the 8½" casing). A further 36 cu.m was continuously mixed and squeezed into the annulus. Subsequent downhole temperature runs indicated the annular flow had been stopped. The well was then deepened to 1296m.

Sleeving Broken Casing

A number of the wells in Wairakei have suffered casing collapses and fractures. When such failures do not unduly restrict the well output or jeopardise the well safety no remedial action is necessary. However, well WK216 was found to have a number of suspected casing breaks between 19 and 147m. The subsequent workover to recondition the well identified casing failures at 107 and 127m. The loss of water through the breaks further implied an incompetent annular cement sheath. The damaged casing was realigned with a tapered casing roller and squeeze cemented with 7

cu.m of cement of which 50% left the casing. Formation cuttings previously blocking the casing were then drilled out and a drillable casing bridge plug was set at 196m. 194m of 7" X/L casing was then run and cemented thus providing a sleeve over the region of damaged 8½" casing. Finally the bridge plug was drilled out. The workover took 10 days.

Downhole Calcite Deposition Removal

While production wells in the Wairakei field have suffered little from in-hole deposition in recent years, the outputs from producing wells in the Kawerau field are affected to varying degrees between different wells. In particular well KA8 suffered a 60% drop in output over a 3 to 4 month period. Simply drilling and scraping the deposition from the production casing and liner restores the well to its original productivity. Occasionally the slotted liner is withdrawn, open hole reamed and those sections of liner with blocked slots replaced.

Generally where calcite deposition is suspected as a cause of well output decline, a series of go-devil runs are made with various diameters of go-devils. The depths to which the go-devils will run without obstruction indicate the magnitude and location of the deposition. The well is slowly quenched with water and, if the deposition is particularly heavy, a small diameter hole is drilled through the deposition to allow cuttings and water to pass down the well. The remaining deposition is then drilled out followed by a trip with a casing scraper. A junk basket is run below the scraper to catch samples of the deposition for petrological examination.

Some years ago a well was acidised in an endeavour to remove calcite deposition. Failure of the corrosion inhibitor resulted in significant damage to the drillstring with suspected attendant damage to the casing. Any future acidising attempts must be preceded by full testing of inhibitors under elevated temperatures.

Reducing Inflow of Low Enthalpy Fluids

Following exploitation of the Wairakei field for over two decades, reservoir pressures have gradually declined. A side effect recently found in a number of wells is a significant flow of cool fluid entering the upper sections of the wells. In some instances, closing a well results in sufficient inflow of these cooler fluids to keep the wells in a quenched condition.

Downhole flow rates in excess of 50 litres/second were measured in Wairakei well WK107 using a downhole spinner. Early in 1980 attempts were made to seal off the inflowing

water thus bringing the well back onto production. After pulling the liner a spinner was run downhole to identify a section of hole with a minimum diameter in which to set a cement plug. A drillable bridging tool was cemented into place at 376m and attempts made to seal the upper section of open hole.

Having established that the tool had sealed the hole some 660 cu.m of gel (thick drilling mud) was pumped into the well without regaining circulation. The upper section of hole was then progressively sealed by placing a 2.25 cu.m cement plug through drillpipe and, after allowing time for cement to set, drilling out the cement with water and pressure testing the well to 2 bars every metre. When the well would not hold the test pressure a further batch of cement was placed. A total of 17 batches of cement were used to effectively seal the upper section of open hole.

The well was then deepened to 647m and has since been brought back onto production for the Wairakei Power Station.

Drilling workovers such as those outlined above often exceed original estimates of time and cost to complete; in extreme cases by as much as 100%. Wells which have been discharged for any period of time often suffer hole instability in the open sections of the well and sealing of permeable strata with cement consumes unpredictable quantities of cement.

Further, the sealing effect achieved by cement plugging appears to deteriorate with time. This may be due to retrogression of the cement with exposure to elevated temperatures or to lack of penetration of the cement into all except the primary permeability. In any event, workovers requiring sealing of the open hole are more effective if a casing is cemented past the unwanted zones. However this action may constrain the ability to carry out further downhole drilling because of the reduction in well diameter.

Dual Completion of a Well

Downhole logging carried out on completion of Ngawha well NG9 indicated good permeability at 673, 935 and 962 metres. The well was drilled 7½" to 1,000m and cased 8½" to 588m. However an internal flow occurs from 673m down the well to the two lower zones. The flow was measured at 2.5 litres/second 5 days after the well was closed. When discharged the well produces up to 526 tonnes/hour with an enthalpy of 990 joules/gram. Apart from the brief 2 day output test the interzonal flow has continued unchecked since the well was completed in April 1979. This has prevented the measurement of the physical properties of the fluid originally in the reservoir below 673m.

A workover is proposed for early 1981 in which an external casing packer will be run to around 850 m on 5½" casing. The annulus between the 5½" casing and 7½" open hole will be cemented for 100m above the packer. The 5½" casing will pass through a gland at the wellhead thus allowing for the 2-2.5m of expansion anticipated from a quenched to a discharging condition. Fig 2 shows the proposed completion. Note the wellhead completion which eliminates the need to allow for expansion of the 5½" casing when connecting pipework for discharge testing.

The proposed dual completion will allow the bottom two permeable features to be flowed through the 5½" casing and the upperzone through the 5½" - 8½" annulus. As the well is expected to stand with water to the wellhead the temperature, pressure, permeability and chemistry pertinent to the upper and lower sections should be able to be separately identified.

Well NG9 is one of two productive wells out of the seven investigative wells drilled to date. The other well, NG4 is also a good producer but suffers from a similar interzonal flow. The dual completion of NG9 should clarify the physical characteristics of the two levels without the need to drill two separate wells into the two zones. Such data will influence how future wells should be completed for optimum performance.

In the meantime, if completion tests on the next well to be drilled suggests that interzonal flow is likely, the well will be completed in a similar manner to that proposed for NG9. However the 5½" casing will terminate above the 8½" casing shoe omitting the wellhead modifications but still capable of isolating the two levels when the well is shut. However some difficulty is expected in separately measuring pressure and chemical characteristics of the individual production zones.

Future Drilling in New Zealand

Both the direction and intensity of future geothermal investigations will depend on the priorities given to other energy developments within New Zealand. While there is potential for a major expansion in geothermal drilling in a number of different reservoirs, constraints such as experienced personnel, statutory clearances and an apparent conflict between energy development and tourism may restrict a massive growth in drilling in some areas.

Currently New Zealand has had Wairakei producing electricity since 1958 and Kawerau only partially developed to supply heat and electricity to a Pulp and Paper Mill. In 1981 the Ohaki Power Station construction should be started for completion in 1986 and it is anticipated that development of the Ngawha field will be accelerated. Preliminary work to gain the necessary clearances to investigate two further fields (Mokai and Ruahine Springs) is underway and similar work for other fields is expected to be initiated within the next two years.

Hopefully the coming decade will see substantial increases in geothermal work in New Zealand.

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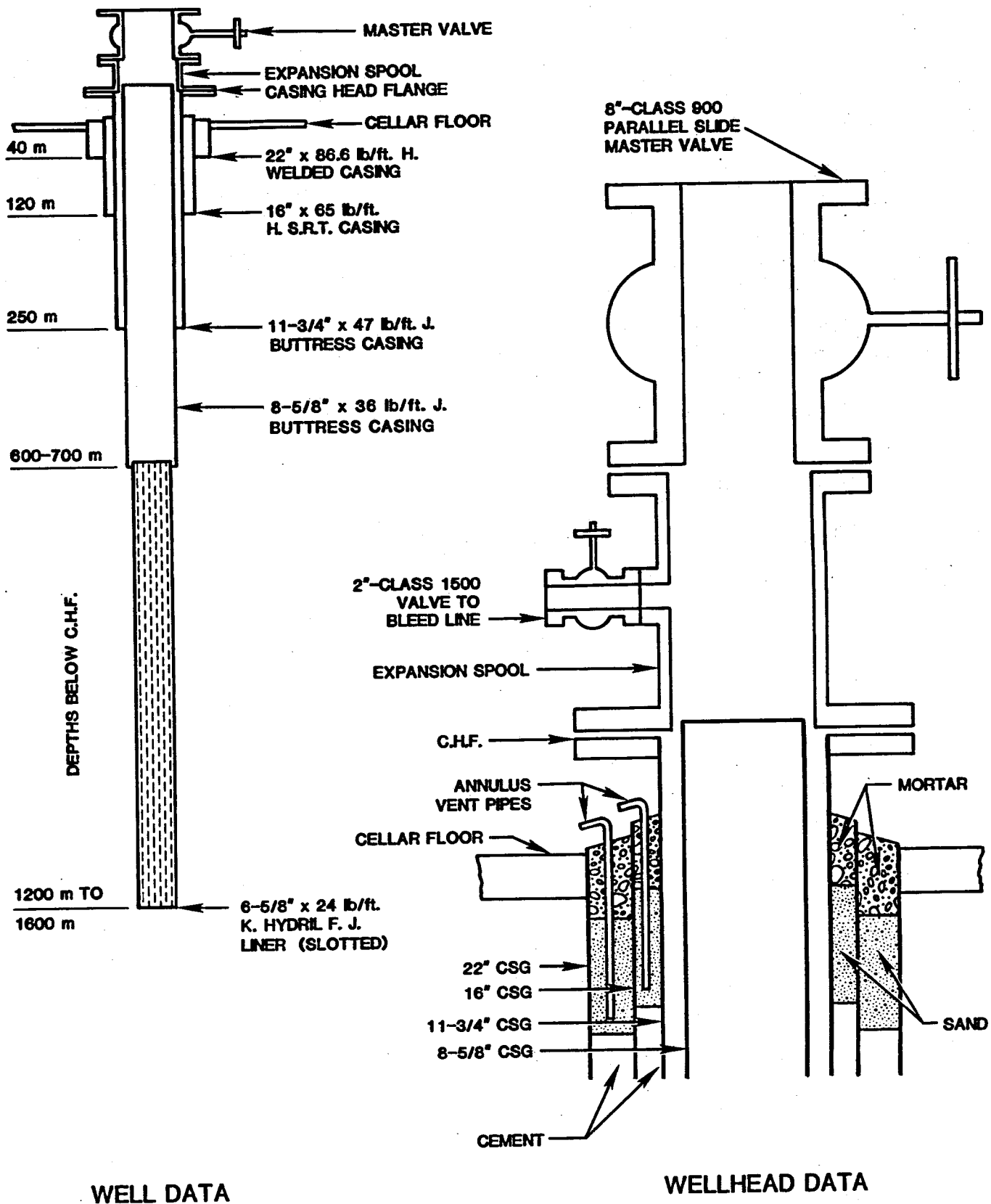


FIG. 1

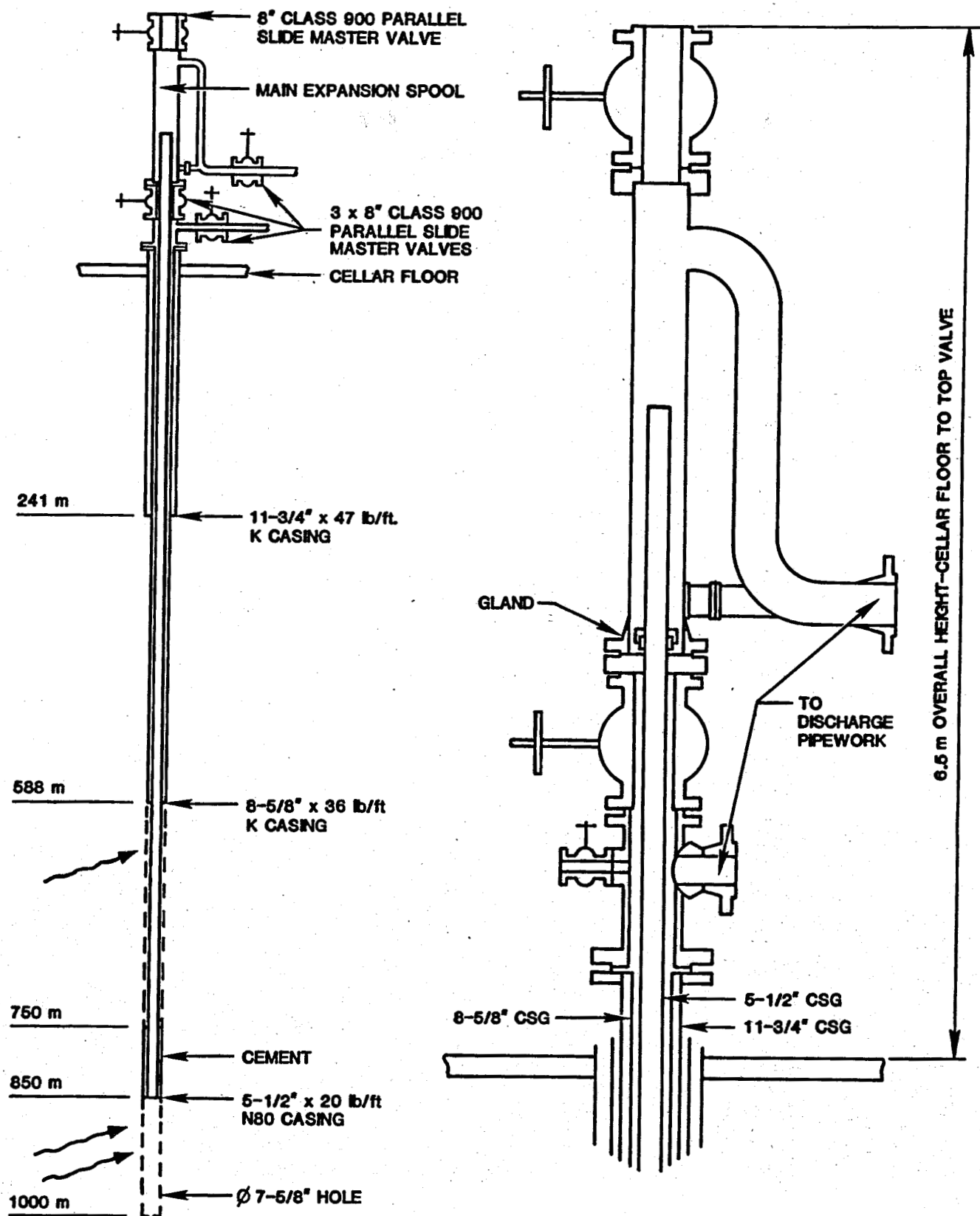


FIG. 2
DUAL COMPLETION OF WELL NG 9